LA-UR -79-747

conf. 790327--35

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SUBMITTED TO: 1979 Particle Accelerator Conference, Accelerator Engineering and Technology, March 12-14, 1979, Sheraton-Palace Hotel, San Francisco, California.

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HIGH INTENSITY BEAM PROFILE MONITORS FOR THE LAMPF PRIMARY BEAM LINES*

E. W. Hoffman, R. J. Macek, C. van Dyck, D. Lee, A. Harvey, J. Bridge, J. Caine†

Abstract

Two types of beam profile monitors[1] are in use at LAMPF to measure the properties of the 800 MeV, 500 μA proton beam external to the linac. Both types use secondary electron emission from a wire to produce a current signal proportional to the amount of proton beam that intercepts the wire. The wire scanner system uses a pair of orthogonal wires which are passed through the beam and the harp system uses two fixed planes of parallel wires. Most of the harps are not retractable and are exposed continuously to the primary beam. The high beam intensities available lead to a number of technical problems for instruments that intercept the beam or are close to primary beam targets. The thermal, electrical, radiation-damage, and material selection problems encountered, and some solutions which have been implemented are discussed.

Introduction

The high intensities of the 800 MeV proton beam at LAMPF impose several restrictions on any device used to monitor the beam profiles. To hold beam loss to acceptable levels, the multiple scattering must be small. The device must exist in the beam where average current densities are as high as 10 mA/cm^2. The high energy density deposited by the beam implies that the device must operate in vacuum, must not be distorted by thermal expansion, must not melt, and must be strong enough to withstand shock waves due to sudden vacuum failures. Since cooling must be by radiation, the emissivity should be high. If the secondary emission process is to provide the signal, then thermionic emission must be a small fraction of the secondary emission current. In addition, the device should be capable of operation for periods of several years in an environment where the radiation dose is 10^8-10^9 rads/year. Since some of these devices must be located under many tons of shielding and are not easily accessible, high reliability is also an important consideration.

Wire Scanners

Design

A wire scanner (Fig. 1) consists of an actuator that moves two mutually perpendicular signal wires through the proton beam in a controlled way. The secondary emission current from the wires is measured as a function of position of the wires. This signal is analyzed to provide centroid and shape information about the proton beam.

The signal wires are 0.004 in diam silicon carbide filaments[2] that are spring mounted to compensate thermal and radiation-induced expansion. To each side of each signal wire, is attached a clearing field electrode that is at a positive potential to ensure complete removal of all secondary emitted electrons (Fig. 2).

The signal wire assembly is moved along a line 45° from the horizontal so both horizontal and vertical profile data are obtained at the same time. The driving force is supplied by a stepper motor and the vacuum seal is an AM350 bellows. The electrical leads and vacuum feedthroughs are mineral (MgO) insulated coaxial cables so all components within 60 cm of the proton beam are quite radiation resistant. The actuator drives the signal wires at 4.8 mm/s along the x and y axes when it is operated at its maximum speed.

*Supported by the U.S. Department of Energy.
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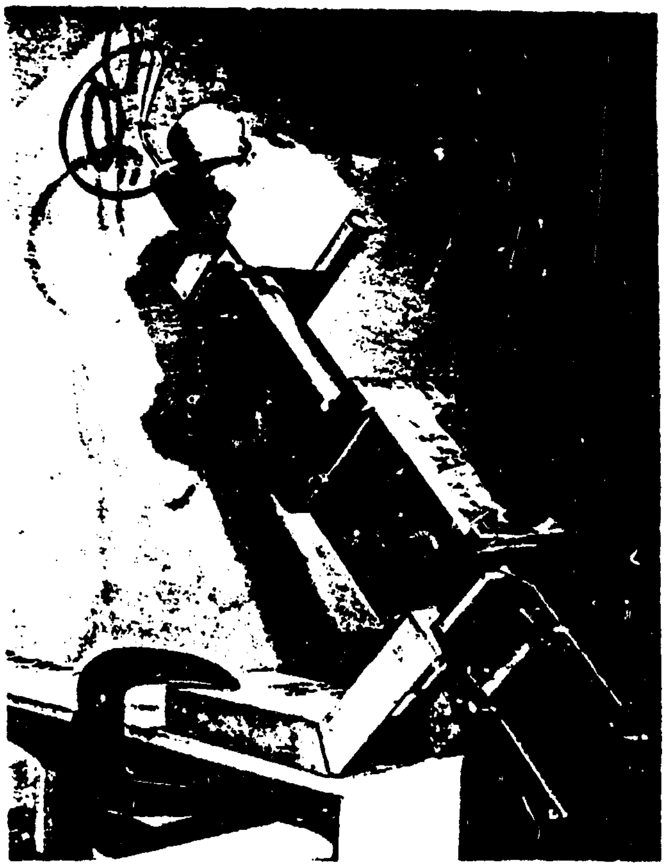

Fig. 1 - Wire scanner assembly.

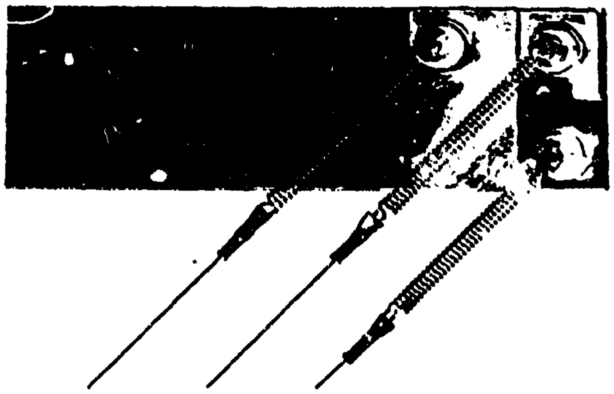

Fig. 2 - Attachment of SiC signal wire (center) and two adjacent SiC clearing field wires to a wire scanner fork.

Operation

The secondary emission current is about [illegible] of the proton beam current that intercepts the signal wire. This current is integrated and digitized for each proton beam macropulse. The computer-controlled data-acquisition system has the capability of subtracting a constant level of background and of averaging several measurements.

Figure 3 shows a set of profiles obtained by several of these devices. The proton beam had a peak intensity of 7 mA and consisted of 550 μs macropulses at 120 Hz. Each point is the average of 16 measurements as the signal wires passed through the beam. Since the actuator stroke is 3 cm, the time required to obtain the data for these profiles is about 6 s.

Conclusions

The silicon carbide wires have allowed use of these devices at beam currents above 360 μA average. The long radiation and nuclear interaction lengths of SiC produce negligible scattered beam (<100 nA), the low density keeps the heating to tolerable levels and SiC is thermally stable to ∿2700°C. The filaments we use have a very thin coating of carbon on the surface so the emissivity is about 0.8 allowing efficient radiative cooling. Still, at currents above 500 μA average, the thermionic emission currents become a problem for small beam sizes. If we can develop reliable 0.001-0.002 in wires and mountings, we can probably push the use of the wire scanners to 1 mA average current.

These devices operate in a vacuum of $\sim 10^{-7}$ torr so there is no problem with collection of ions from beam-gas collisions.

The electronics[3] used for integration and amplification provide excellent signals for average beam currents as low as 0.1-1 μA.

Data-acquisition time is acceptable and up to six wire scanners can run simultaneously producing data for 12 profiles in about 6 s. The overhead for transmitting this data between computers and displaying it is considerably greater and could profitably be reduced.

The use of ceramic insulators, mineral-insulated cables and feedthroughs, and bellows and Al O-ring vacuum seals has produced an acceptably radiation-hardened device. Maintenance is minimal and consists primarily of radiation-resistant oil lubrication of the moving parts and occasional replacement of worn parts. The only SiC signal-wire failure in ∿2 years was due to melting of the solder connection to the actuator by an ion pump discharge in an abnormally high pressure vacuum.

Harps

Design

The harps (Fig. 4) consist of two orthogonal planes of signal wires and three planes of clearing field wires at a potential of 57 V. The signal wires are attached to alumina ceramic substrates via silver-based printed circuit inks. The ceramic boards and the clearing field planes are mounted on a central stainless steel frame. This assembly hangs from a vacuum-sealing lid that contains the electrical feedthrough for each signal wire. A pair of p.c. edge connectors is mounted on the atmospheric-pressure side of the lid.

The potentials developed on the signal wires range up to 5 V for our readout system. This potential tends to inhibit secondary emission in a nonlinear way[4] for the various parts of the profile. A potential of 0.5 V produces a 40% reduction in secondary emission current if the clearing field is not present.

Both carbon and silicon carbide filaments have been used as wires. The carbon filaments are easily prestressed and soldered to the printed lands but suffer from low strength since the maximum diameter commercially available is 0.002 in. We are presently using 0.004 in diam silicon carbide filaments with a tensile strength of ∿4 X 10^5 psi. The wire is mounted by crimping a copper adapter to each end of the wire and using a spring to maintain 1-2 X 10^5 dynes of tension while absorbing elongations up to 0.1 in. Figures 2 and 5 show these mounting details.

Operation

The secondary emission current flowing to each wire is integrated on the capacitance of the coaxial cable

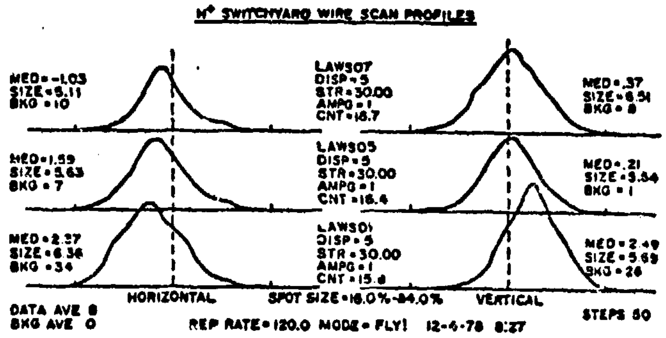

Fig. 3 - Wire scanner profiles. The tick marks on the horizontal axis are 1 cm apart.

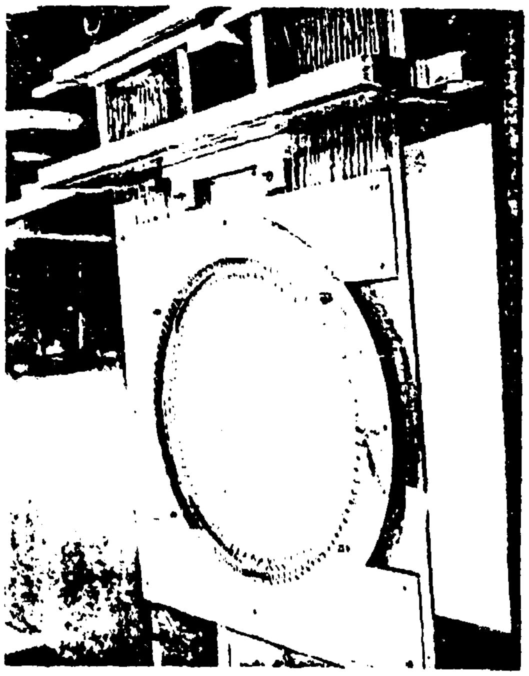

Fig. 4 - Harp assembly. Inner diameter is 33 cm.

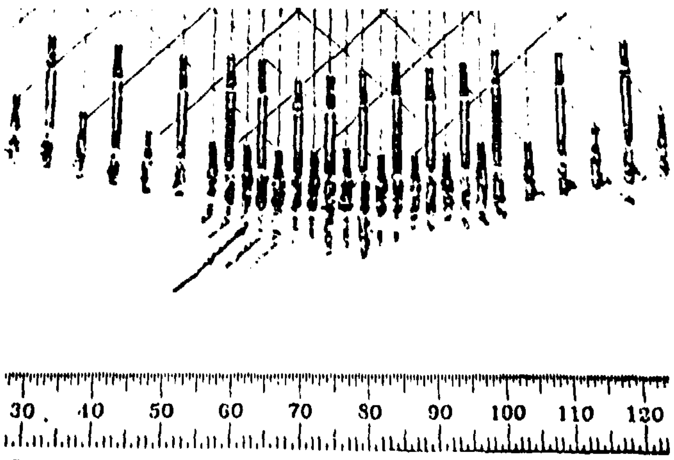

Fig. 5 - Details of spring mounting. Scale is mm.

attached to the signal wire. The resulting signals are multiplexed[5] by FET switches to an amplifier, A/D converter and into a PDP 11/10 computer. The computer continually cycles through the list of selected harps, discharges the cables, acquires data, and stores it in memory. A background subtraction is performed if it has been requested.

When the PDP 11 receives a request for data from the main control computer, it transmits the requested data immediately if no parameters need to be changed. If new parameters are sent to the PDP 11, then new data must be acquired before the return transmission. A sample data display is shown in Fig. 6.

For average proton beam currents of 500 µA, the cable capacity is discharged, the induced signal current is integrated for 2 or 4 macropulses and the voltage on each cable is then read without any amplification. For currents below 5 µA, integration times as large as 1 s are used with additional amplification up to 25X. The ambient noise level limits useful gains to 25X. When integrating for times that are an appreciable fraction of 1 s, the background subtraction becomes quite important since the FET switches have leakage currents as large as 1 nA. The minimum measurable beam current is about 10-100 nA if the beam spot is ≲1 cm wide.

Conclusions

The harps perform as required for current levels from ~1 to ≳675 µA average proton beam currents. Most difficulties are associated with the thermal loads, gas flow forces and radiation damage to which the devices are subjected. These difficulties are manifested by loss of signal wire or by failure to transmit the signal from the wire to the data acquisition electronics.

The soft solder melting point of ~200°C has been exceeded at times, resulting in loss of mechanical joints. The present emphasis is on crimping, spot welding, and a type of hook and eye construction.

Initial construction utilized carbon filaments as wires because of their refractory nature and large radiation length. The 0.002 in diam filaments that are commercially available had insufficient strength to withstand the forces associated with rapid pressure changes in the vacuum system. Silicon carbide filaments with a thin carbon coating were substituted for the carbon filaments. Since SiC elongates ~1% when subjected to hadron fluences of $\sim 10^{20}$ cm^{-2}, it was necessary to develop the aforementioned method of spring loading the wires to maintain tension. The great tensile strength of the SiC is adequate to prevent breakage by sudden loss of vacuum in most cases.

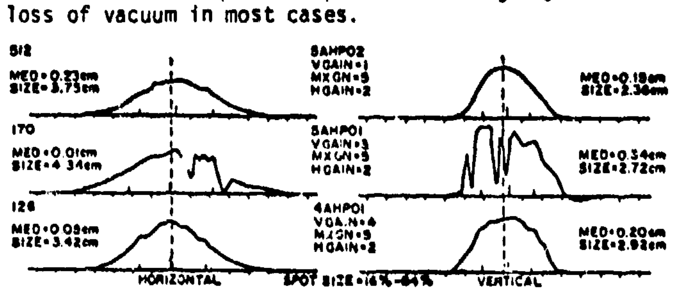

Fig. 6 - Harp data displays. Tick marks below the axis are 1 cm apart. Ragged profiles are due to low insulation resistance of several cables and vacuum feedthroughs.

The ceramic insulated electrical feedthroughs perform quite well when dry, but are prone to exhibit low resistance when they become damp. The question of how to build a radiation-hardened, moisture-proof electrical connector or vacuum feedthrough is still being examined.

The reliability of the edge connectors has been a continuing source of difficulty. A quantity of molded ceramic connectors were originally obtained. Shrinkage was difficult to control and breakage was a problem. There were indications that they were susceptible to the same moisture problems mentioned for the ceramic insulated feedthroughs. Due to our inability to obtain more of these connectors, we are now pursuing the use of plastic connectors. A promising material is Ryton[6] which is reported to show no change in properties for a radiation dose of 5×10^9 rads. Our improved knowledge of the dose levels at the harp locations indicates that this plastic may survive for periods of five years or more.

The signal cables that connect to the harp are either RG-174 or mineral-insulated coaxial cable. The mineral-insulated cable is rather unreliable due to the difficulty of producing and maintaining a good hermetic seal at each end of the cable. We are presently pursuing improved radiation-resistant plastic insulated cables and are using RG-174 since it will probably survive for at least a few years at most locations. The increased reliability of the RG-174 has overriden the high radiation resistance requirements for the present.

We note two environment requirements for the harps. If the beam-line pressure rises to ≳10 µm, the ionized gas begins to make appreciable contributions to the harp signals and the profiles are no longer faithful representations of the proton beam. Also, if the harps are not adequately protected from the secondary particles produced in targets or beam stops, secondary emission from the relatively large printed lands on the ceramics becomes an appreciable signal and badly distort the desired result.

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6. Registered trademark of Phillips Chemical Company, a polyphenylene sulfide resion.